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ULTRASONIC SCANNING SYSTEM FOR INSPECTION OF BRAZED TUBE JOINTS

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16. ABSTRACT

Described herein is the Ultrasonic Scanning System used to inspect and evaluate in-place brazed tube joints. Because of the expanding use of brazed fittings in the Aerospace field the Ultrasonic Scanning System was designed, developed, and built especially for nondestructive testing. It was selected because of its known response to brazing defects not associated with material density changes.

The developed scan system is capable of scanning brazed joints in union, tee, elbow, and cross configuration of 3/16-inch through 5/8-inch diameters. The system is capable of detecting brazed defects as small as 0.008 by 0.010-inch which exceeds the 0.015-inch diameter defect resolution required by specification.

The ultrasonic brazed tube scanner is recommended for the evaluation of all brazed tube joints that are within its dimensional capabilities and for which an inspection is desired. This recommendation is based upon the in-place scanning and the rapid inspection time capabilities of the system and the innate ability of ultrasonic test methods to detect defects which are not related to material density changes.

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SUMMARY

Described herein is the Ultrasonic Scanning System used to inspect and evaluate in-place brazed tube joints. Because of the expanding use of brazed fittings in the Aerospace field the Ultrasonic Scanning System was designed, developed, and built especially for nondestructive testing. It was selected because of its known response to brazing defects not associated with material density changes.

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TECHNICAL MEMORANDUM

SECTION I. INTRODUCTION

A. GENERAL

This report describes an Ultrasonic Scanning System that was developed by the (MSFC) Quality and Reliability Assurance Laboratory for evaluating brazed tube joints. This ultrasonic system for nondestructive testing (NDT) was designed, developed, and built because of the method's effectiveness in evaluating brazing defects not associated with material density changes.

This report also describes the five major items of equipment that comprise the system. Figure 1 shows a photograph of all of the major items of equipment, and Figure 2 is a block diagram that presents the relationship and signal flow. The major items of equipment, all covered in this report, are:

1. Scanner
2. Limit Control
3. Flaw Detector
4. C-Scan Converter
5. Storage Detector

Subsequent sections contain an overall description of the Ultrasonic Scanning System, its capabilities and limitations, and the theory of ultrasonic inspection techniques.

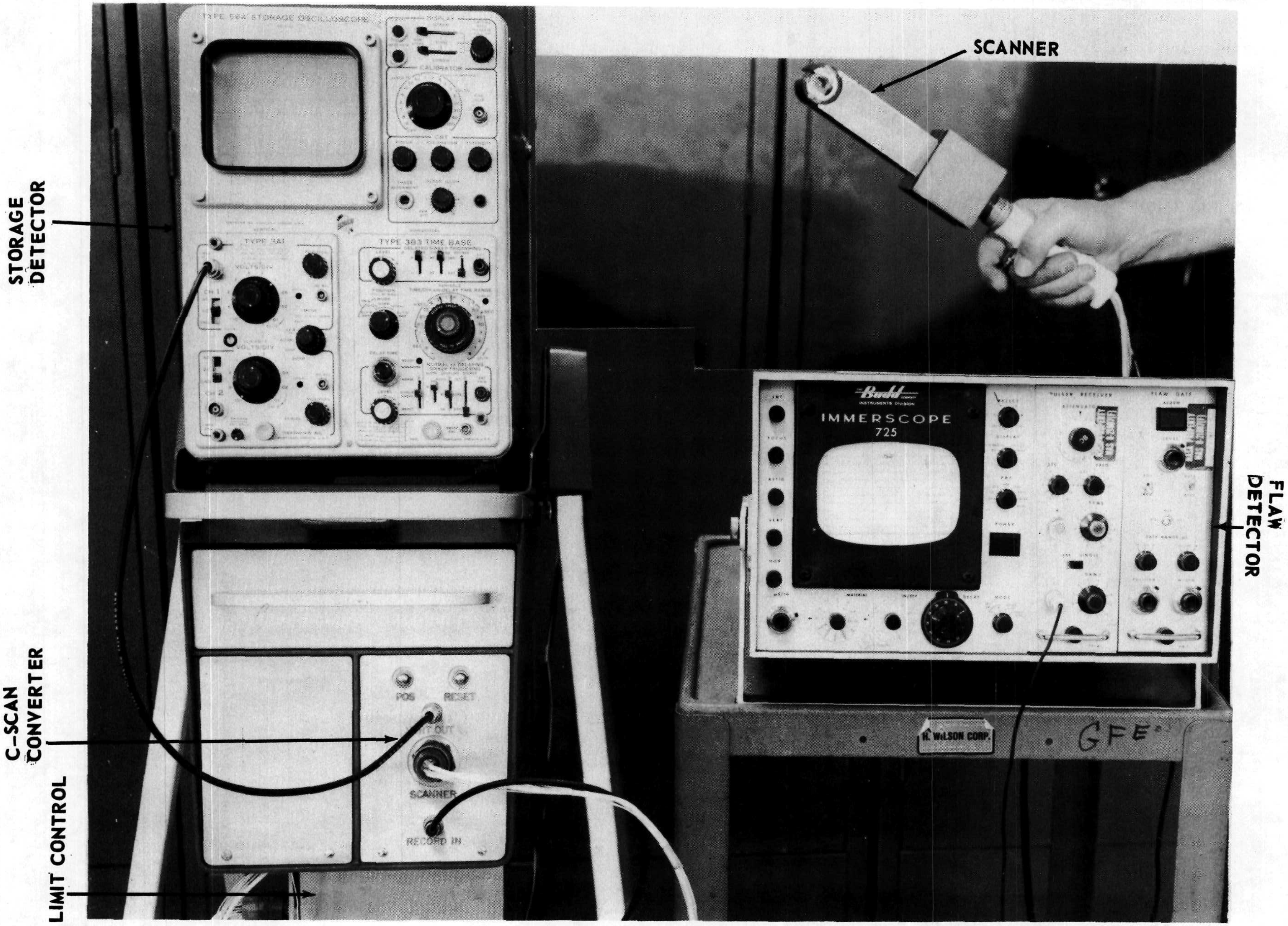

Figure 1. Ultrasonic Brazed Tube Inspection System Components.

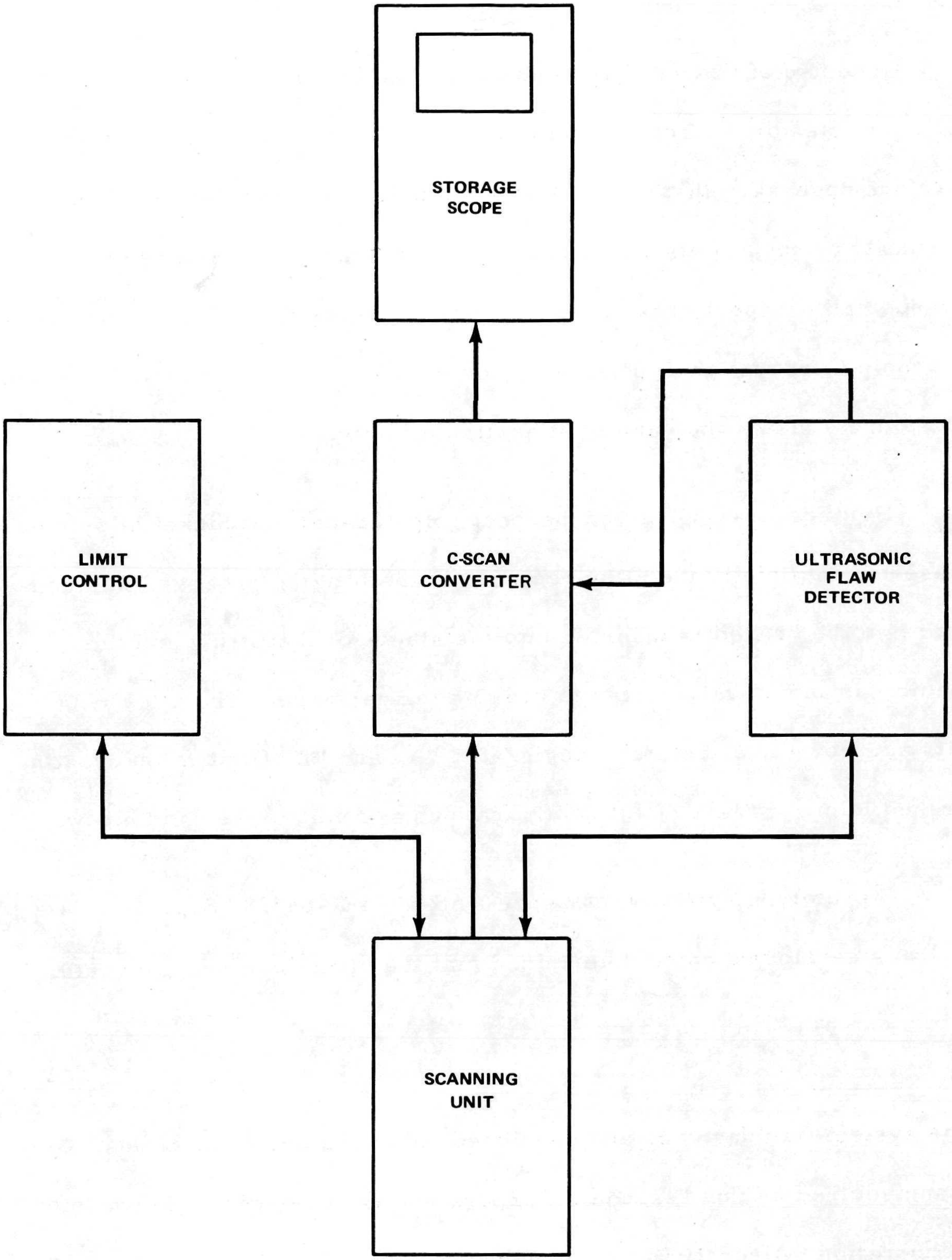

Figure 2. Ultrasonic Brazed Tube Inspection System Block Diagram

B. BACKGROUND

The use of brazed fittings in the aerospace field and particularly at MSFC has steadily increased and is expected to expand further. It was therefore necessary that methods and equipment be provided for ensuring the quality of such joints. The brazed tube scanner was designed to ultrasonically inspect brazed joints typical of those manufactured by the Aeroequip Corporation*. Figure 3 shows a tube cross section and dimensions, and Figure 4 shows the variety of available joints.

Prior to brazing, an 82-percent gold, 18-percent nickel alloy ring is inserted into the braze alloy recess. In the brazing process, the tube which is to be brazed is inserted into the sleeve of the fitting and the assembly is inductively heated to brazing temperature. The alloy ring melts and flows into the areas designated "A" and "B" (figure 3), creating a brazed joint. Brazed joint configurations are union, tee, and elbow.

A prototype system (reference NASA TM X-64558, September 14, 1970) was developed which determined that the ultrasonic system could

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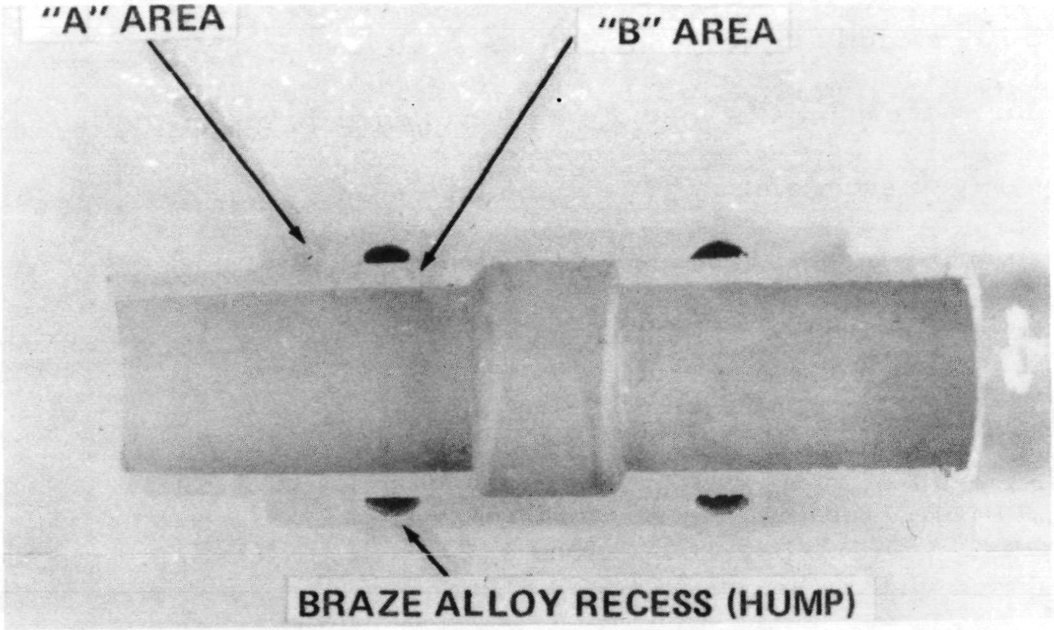
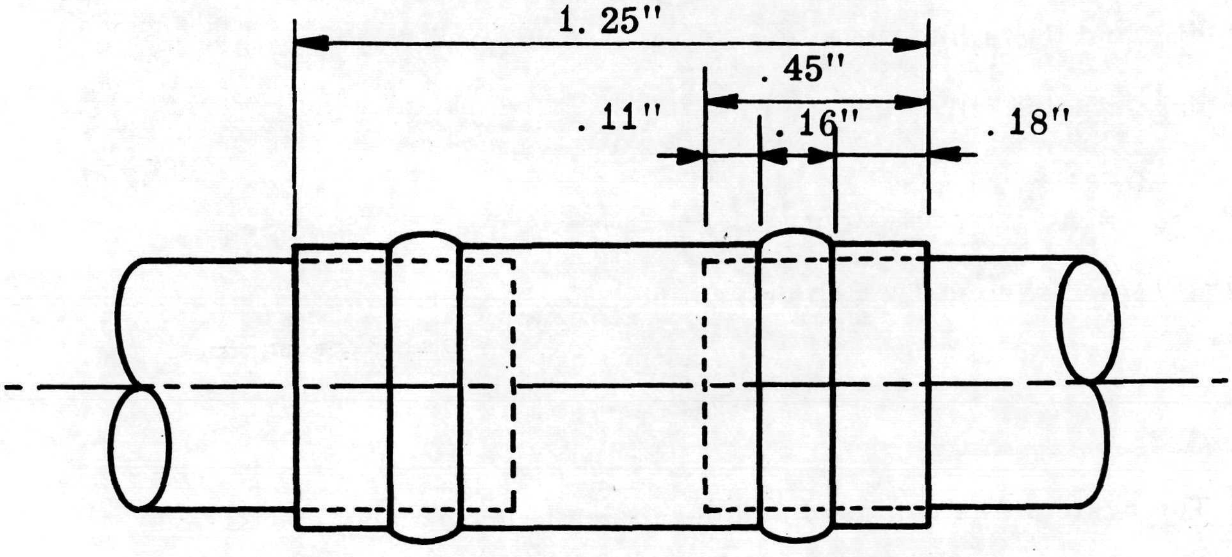
* The system was designed and developed using brazing connections manufactured by the Aeroequip Corporation as standards. (Aeroequip Corporation, Aircraft Division, Elbecco Plant, Jackson, Michigan.) However, any brazed tube connection within the size capability of the system can be nondestructively inspected.

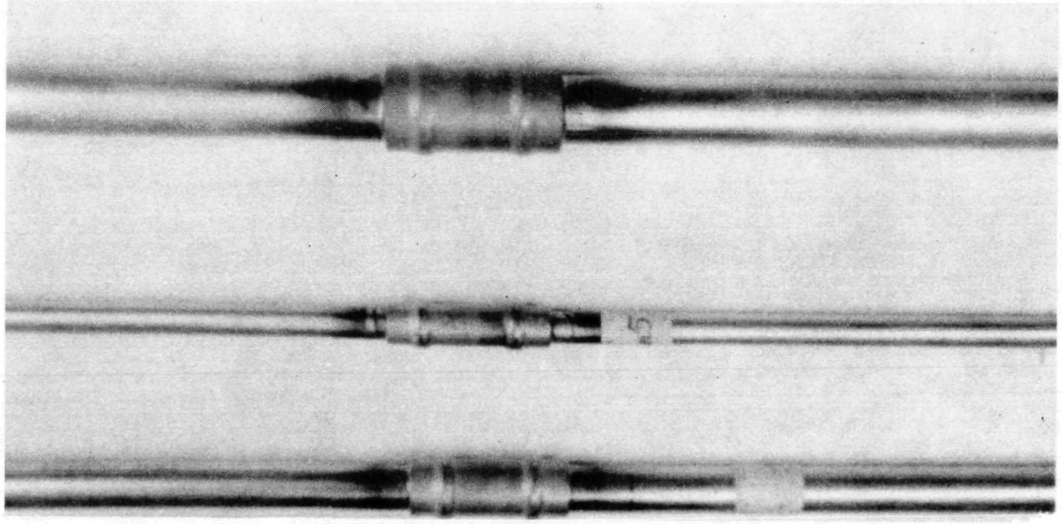


CROSS-SECTION OF 1/2-INCH TUBE JOINT

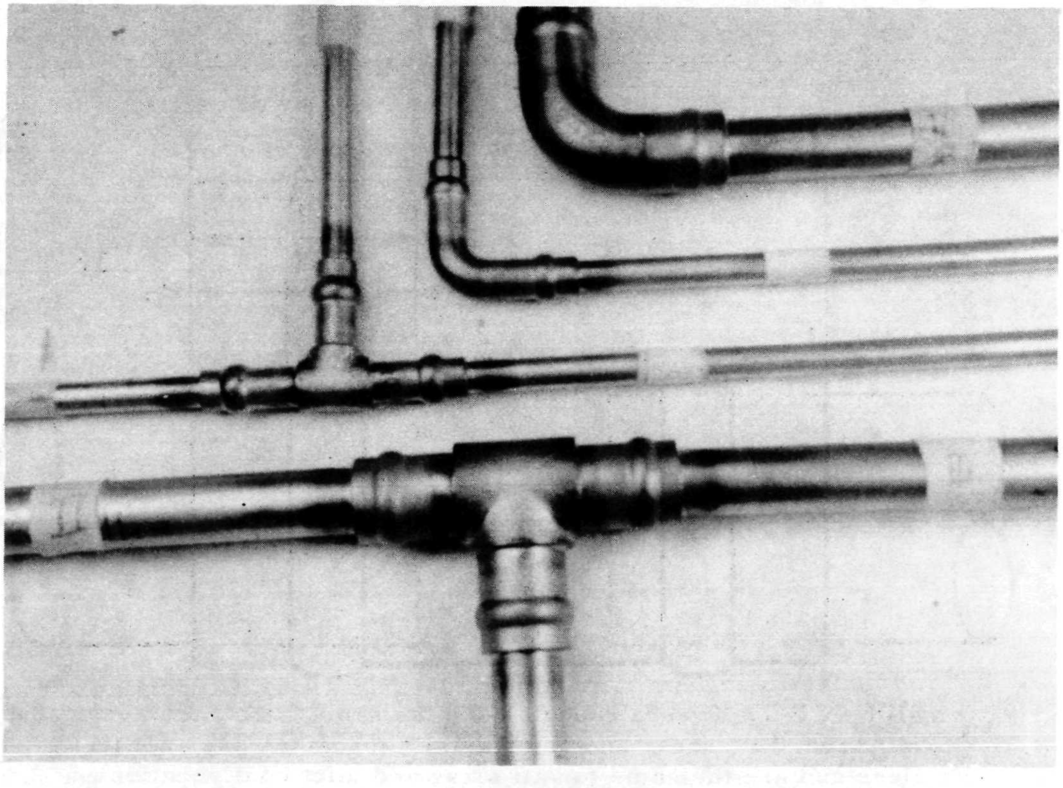


UNION JOINT. (Overall lengths are the same for all size unions. "A" area, "B" area, and hump axial dimensions are average values and are the same for all sizes and joint configurations.)

Figure 3. Construction Details of a Brazed Joint.



3/8-, 1/4-, AND 1/2-INCH UNIONS



1/2- AND 1/4-INCH TEE AND 90-DEGREE ELBOW JOINTS

Figure 4. Typical Brazed Tube Joints.

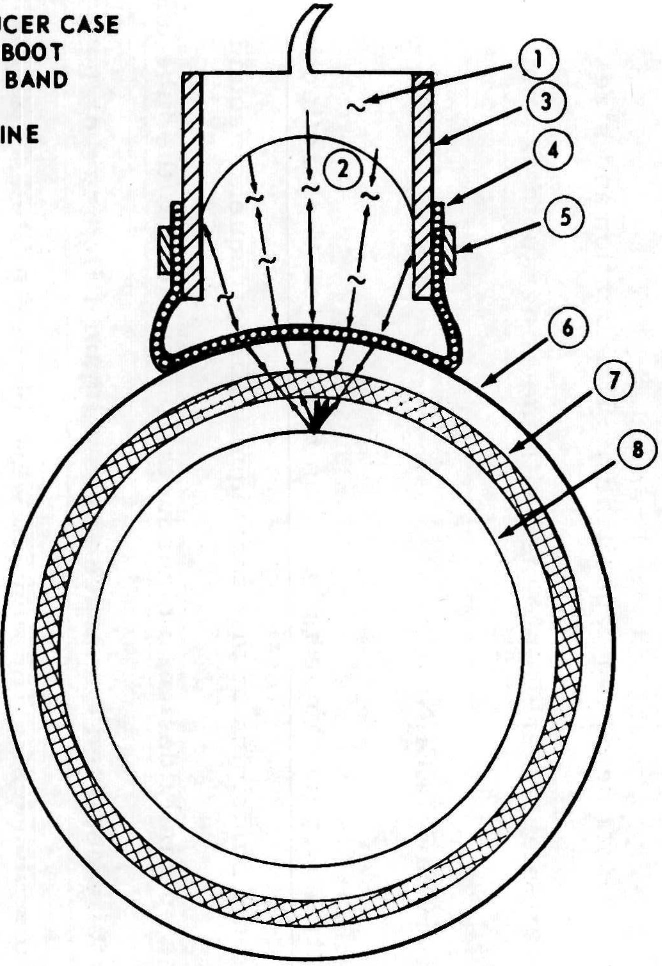
effectively detect flaws in brazed tube joints. Because the prototype was designed to inspect brazed joints on a particular piece of equipment, it was too large to be of universal use. Therefore, it was deemed desirable to develop a system that could inspect any joint that could be brazed in-place. The system described in this report was manufactured to inspect any in-place brazed tube joints that range in diameter from 3/16-inch through 5/8-inch. The system was developed under the philosophy of: "if it can be brazed, it can be inspected;" and it meets all of the specifications and requirements dictated by that philosophy.

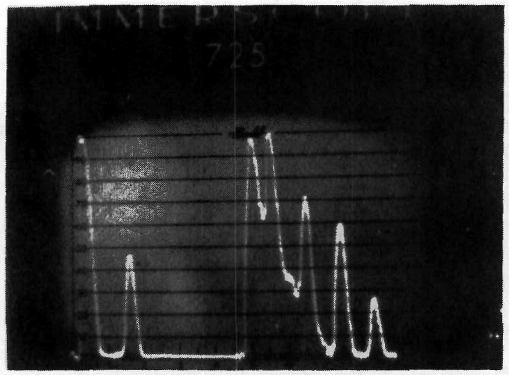
The evaluation of the scan system considered both the operational characteristics and the defect detection capabilities. The system was evaluated for ease of operation, scan times, and joint configuration adaptability and defect detection capabilities. The location and size determinations of defects were confirmed with metallographic examination.

C. ULTRASONIC TECHNIQUE

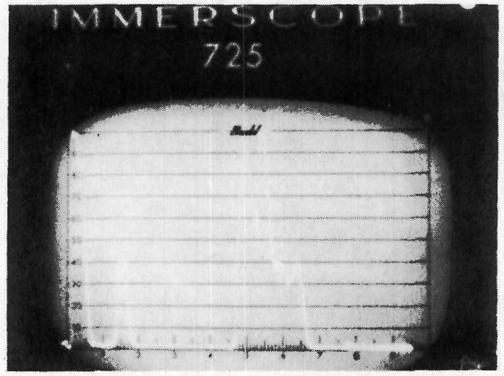
The ultrasonic technique is based on the loss-of-back reflection. Figure 5 shows the principles of this technique. High-frequency sound energy from the specially designed transducer is focused into the tube under test. The specially designed transducer uses a liquid-filled rubber boot to simulate an immersion test. The focused wave is transmitted through the liquid into the tube joint and is reflected from the back surface of the tube. A loss-of-back reflection from the tube's inside diameter, because of a discontinuity in the sound path, is an indication of a defective brazed area.

1. TRANSDUCER, 8MHz, 0.3" FOCAL LENGTH
2. WATER
3. TRANSDUCER CASE
4. RUBBER BOOT
5. SEALING BAND
6. SLEEVE
7. BRAZE LINE
8. TUBE





GOOD BRAZE – GOOD BRAZE IS INDICATED BY THE RESOLUTION OF THE BACK SURFACE OF THE TUBE. SIGNAL FROM 0 TO 2 (SCOPE SCALE) IS THE MAIN BANG. SIGNAL FROM 4.8 TO 6.0 INDICATES SOUND WAVE REFLECTIONS FROM THE RUBBER BOOT SLEEVE INTERFACE. SIGNALS AT 6.5, 7.5, AND 8.25 ARE REFLECTIONS FROM THE BACK OF THE TUBE.



DEFECTIVE BRAZE – DEFECTIVE BRAZE WILL BLOCK THE SOUND WAVE AT THE DEFECTIVE AREA RESULTING IN NO REFLECTIONS, OR VERY WEAK ONES, FROM THE BACK OF THE TUBE.

Figure 5. Ultrasonic Operation with Representative Scope Traces of Good and Bad Braze.

SECTION II. DEFECT TYPES

A. QUALITY REQUIREMENTS

The criticality of a defective area, and therefore the minimum defect which can be allowed in a brazed joint, varies depending upon the number of defective areas, the location of the defective areas, and the axial length of the areas. The ultrasonic scanning system is capable of accurately locating and sizing defective areas and also has sufficient sensitivity to detect the maximum allowable defective area. The maximum allowable defective area is two defects in an axial line whose total axial length does not exceed 0. 062 inch. The smaller of the two areas must not exceed 0. 015-inch axially. Therefore, the smallest single area which must be detected is 0. 015-inch in diameter, and the system meets this requirement.

B. DESCRIPTION OF DEFECTS

Defects in a braze line between the sleeve and tube may or may not process a density difference. Ultrasonics is equally effective in either case. Some braze line defect conditions are:

1. <u>Lack of braze (tube and sleeve centerline parallel and relatively concentric)</u>. In this condition, the braze alloy has failed to flow out of the recess to completely cover the "A" and "B" area circumferences because of contamination and improper brazing. (Figure 3.)

2. Lack of braze (tube and sleeve eccentricity). In this condition, the braze alloy has tried to flow into the "A" and "B" areas for a full 360 degrees but has been physically restricted because the braze gap was too thin at one point around the circumference. Hence, the braze line is correspondingly thicker 180 degrees from the thin point.

3. Cold braze. In this condition, the braze alloy has flowed out into the "A" and "B" areas but has not bonded to either the tube or sleeve.

SECTION III. SYSTEM DESCRIPTION AND OPERATION

A. DESCRIPTION

1. Overall

The system consists of two hand-held scanners that are capable of inspecting tube joints that range in diameter from 3/16-inch through 5/8-inch. Except for size, the scanners are identical in construction. Figure 6 shows a typical scanner from the scanning head to the electrical cabling. Figure 7 shows an overall view of the scanner with the cover removed.

There are three scanning heads for inspecting brazed tube joints of the following sizes:

- Head A -- 3/16-inch and 1/4-inch
- Head B -- 5/16-inch and 3/8-inch
- Head C -- 1/2-inch and 5/8-inch

The scanner that contains scanner head A is designed for inspecting only 3/16- and 1/4-inch brazed tube joints. Another scanner accommodates both head sizes B and C.

The system is made up of the following components (figure 1):

- Scanner
- Limit Control
- Flaw Detector (Budd Immerscope)

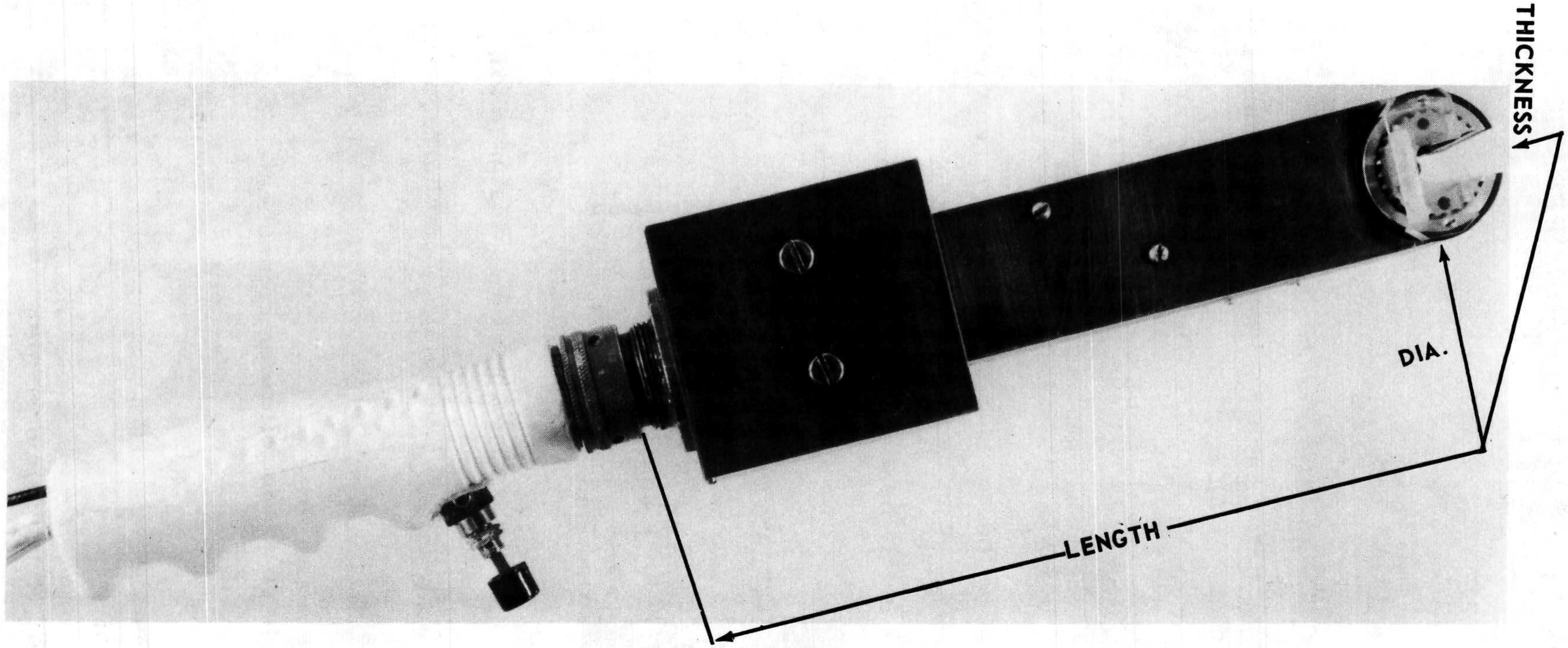


Figure 6. A Scanner, Indicating the Planes of Length, Diameter, and Thickness.

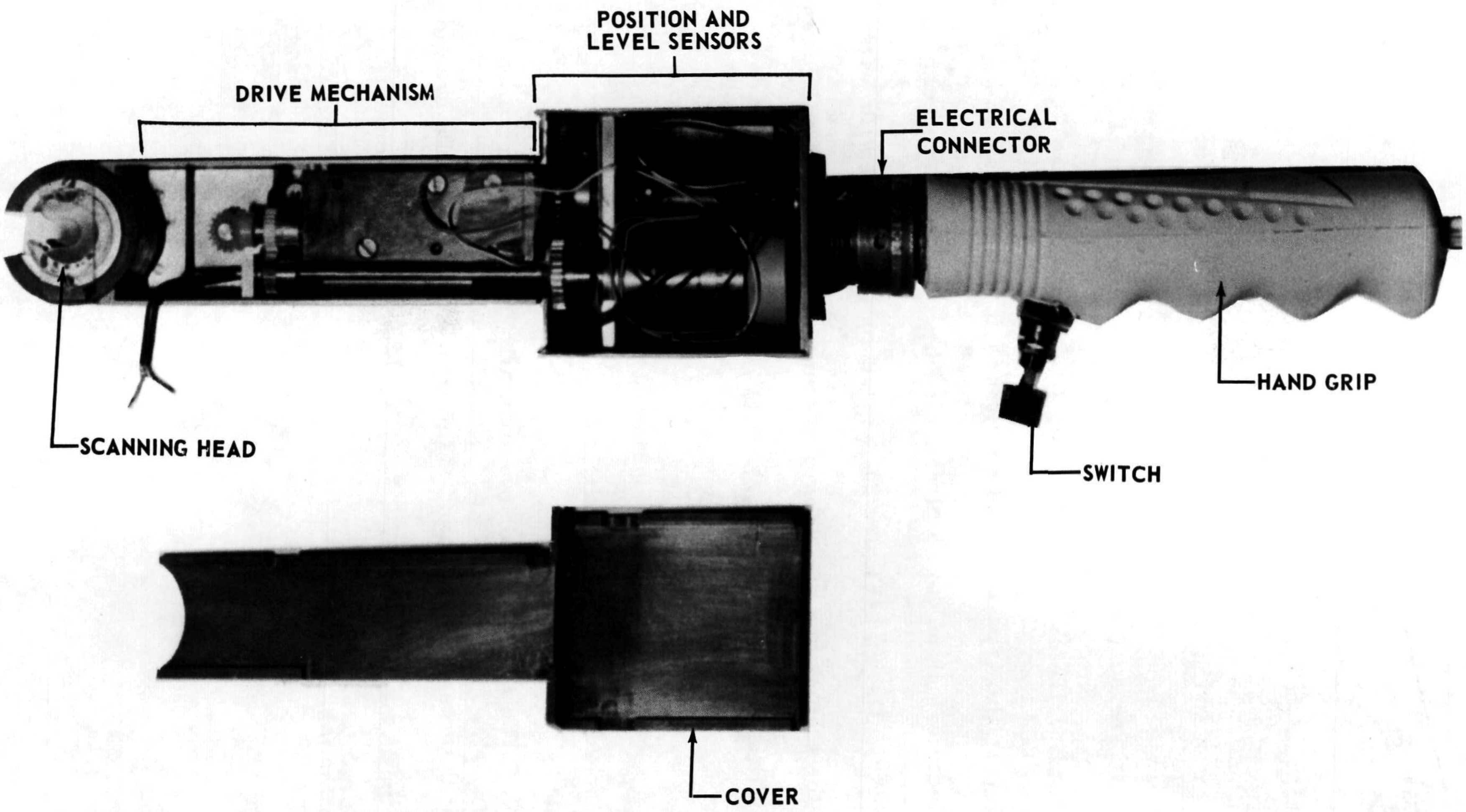


Figure 7. Scanner with Cover Removed.

- C-Scan Converter
- Storage Detector (Tektronix Storage Oscilloscope)

2. System Components

a. Scanner

The scanner is a hand-held unit that contains the ultrasonic transducer, a drive mechanism, position and level sensors, and a hand grip. (Figure 7.) The transducer is an ultrasonic crystal assembly that converts an electrical signal to an ultrasonic pulse and a return echo pulse to an electrical signal (Figure 8). A rubber boot filled with water is attached to the transducer and provides sound wave transfer and focusing media. Flexibility is provided by the boot to conform to tube joint variations.

b. Limit Control (Figure 1)

The limit control is a specially designed electronic component that detects the movement of the transducer along the brazed tube that is being inspected. It reverses the transducer movement after a selected number of turns.

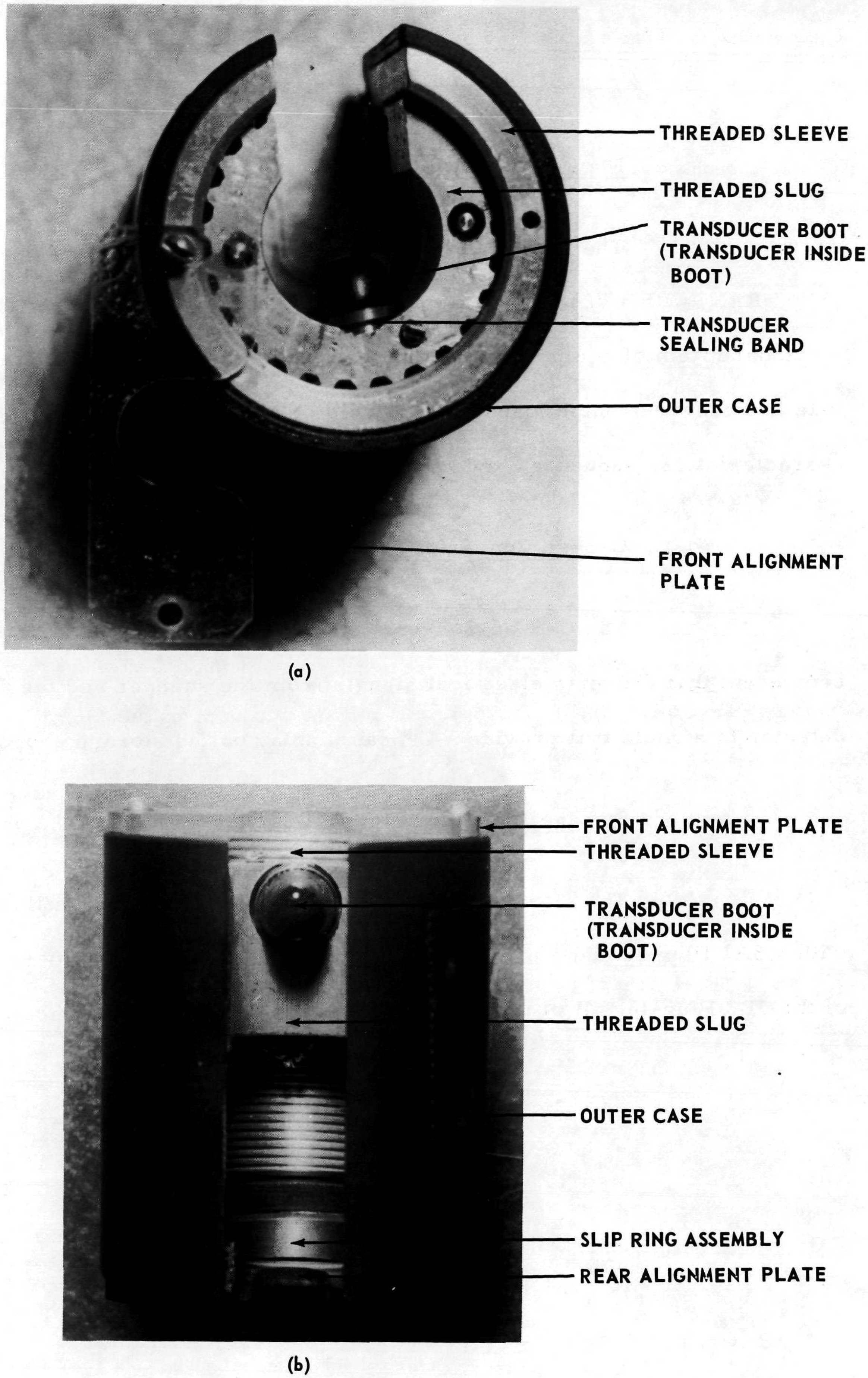


Figure 8. Scanner Head. (a) Top View. (b) Side View.

c. Flaw Detector (Figure 9)

The flaw detector is a Model 725 Budd Immerscope (TEKTRAN) with a 725R1 Pulse Receiver and an FG-2 Flaw Gate. This is a standard item of equipment, and any commercial flaw detector with flaw gate and recorder output capabilities could be used, but the operating characteristics, sequence, and setup parameters must first be verified.

d. C-Scan Converter (Figure 1)

The C-Scan Converter is a specially designed electronic component that converts electrical signals from the scanner and the flaw detector to signals that provide a C-Scan display on the storage scope.

e. Storage Detector (Figure 10)

The storage detector is a Type 564 Storage Oscilloscope with a 3A1 Plug-In and a modified 3B3 Plug-In. Except for the modification of the 3B3 Plug-In, all of the storage detector is standard equipment.

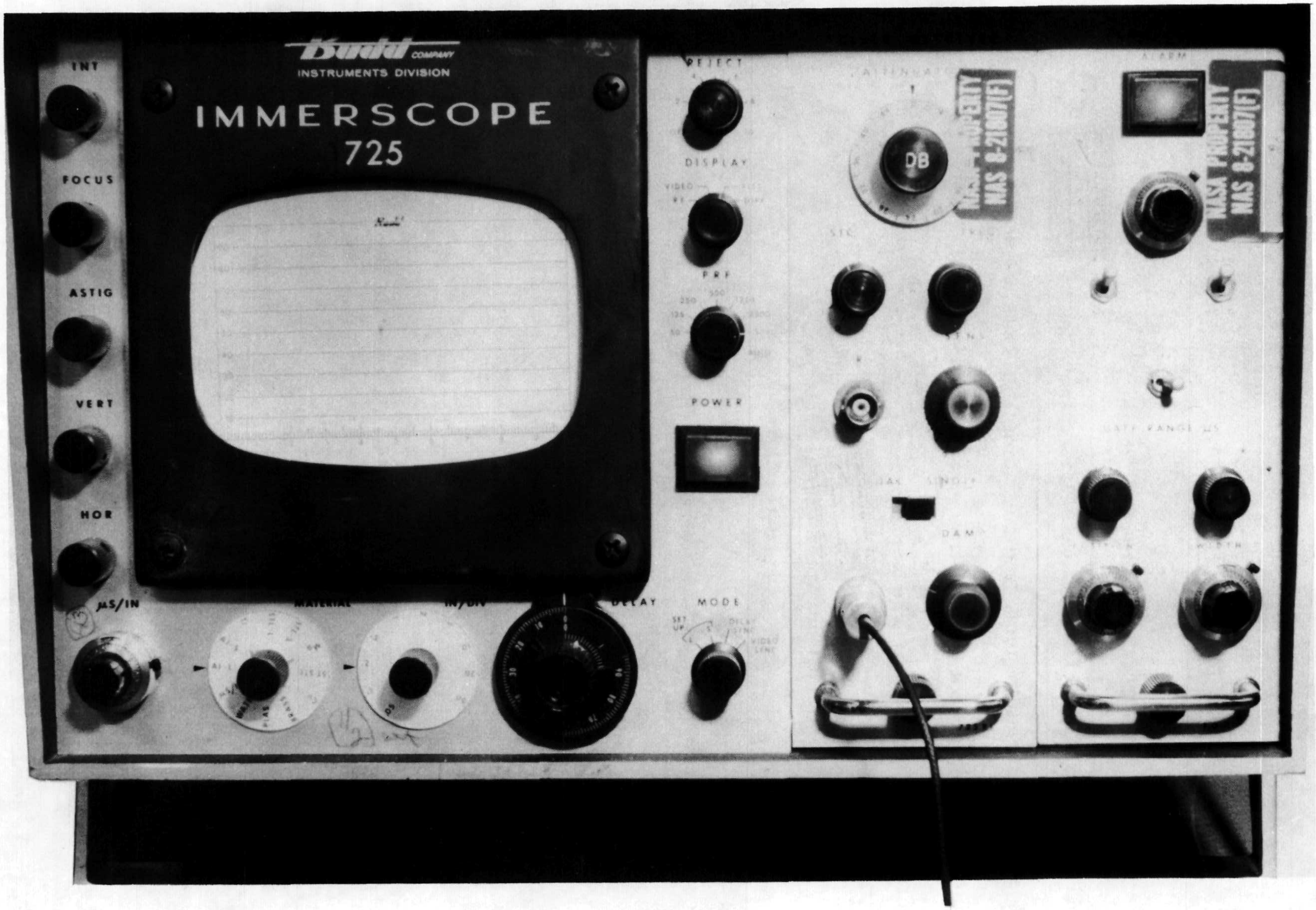


Figure 9. Flaw Detector. (Budd Immerscope Model 725.)

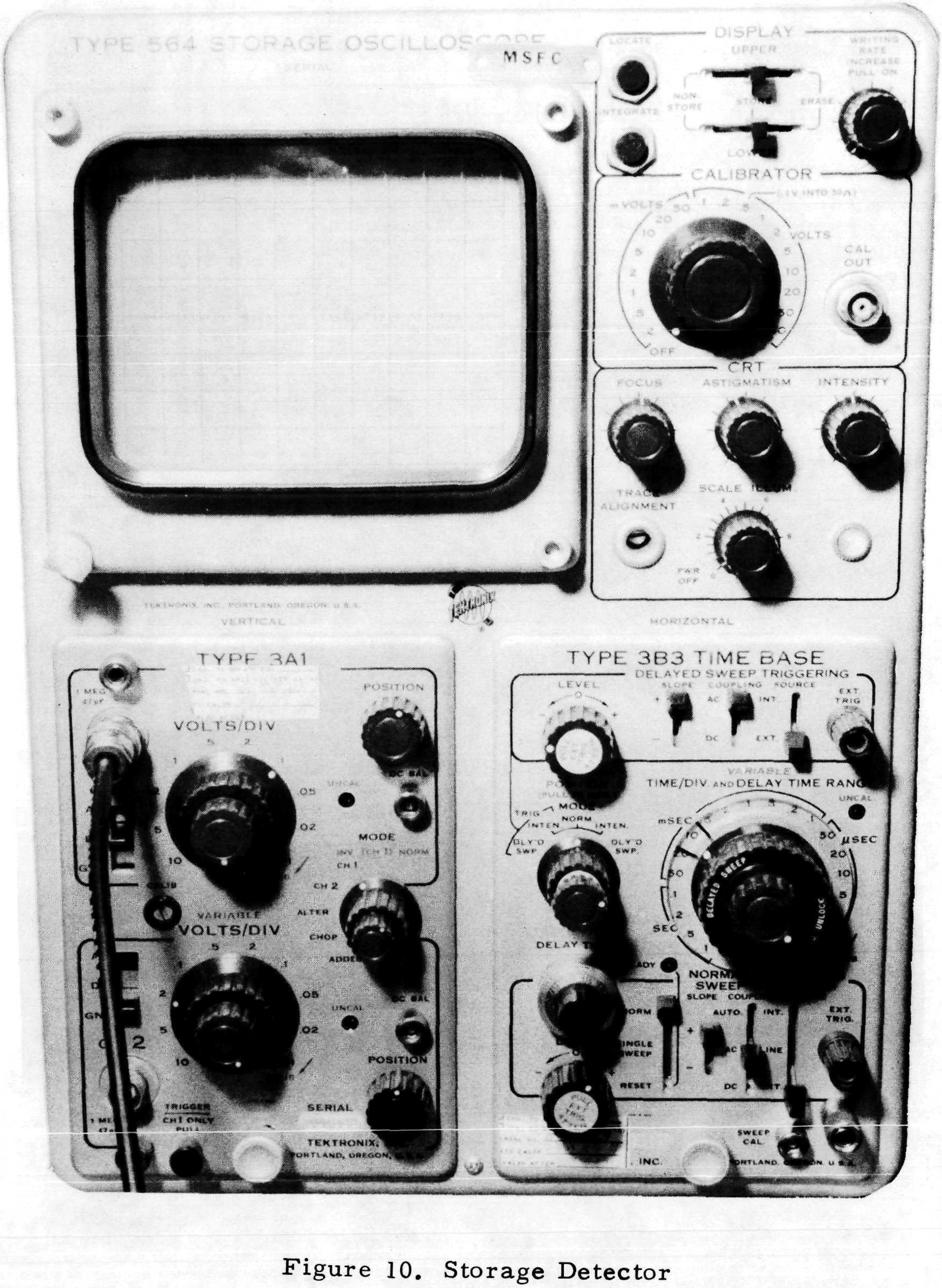


Figure 10. Storage Detector

B. OPERATION

1. Scanner. The scanner (Figure 6) provides the X-Y scan movement across the area under inspection. This is accomplished by rotating the transducer in a circumferential motion around the tube joint while traveling down the tube in a longitudinal direction, thus generating a continuous helix pattern (figure 11). One circumferential revolution corresponds to one X-scan pass, and the travel down the tube is the Y-moveover or travel as in conventional X-Y scanning modes. The scanner was designed for a center-to-center direction between circumferential passes of 0.031 inch. The transducer is an ultrasonic crystal assembly that converts an electrical signal to an ultrasonic pulse and a return echo pulse to an electrical signal.

a. Scanning Head (Figure 8). The scanning head contains a threaded sleeve, a threaded slug, the ultrasonic transducer, a slipring assembly, a tube alignment assembly (front and real alignment plates), and the outer case.

The components that make up the scanning head and their operation are described in the following paragraphs.

(1) Tube Positioners and Guides (Figure 8)

These are variable position tube guides consisting of front and rear alignment plates. Their purpose is to position the brazed tube joint in the center of the slug.

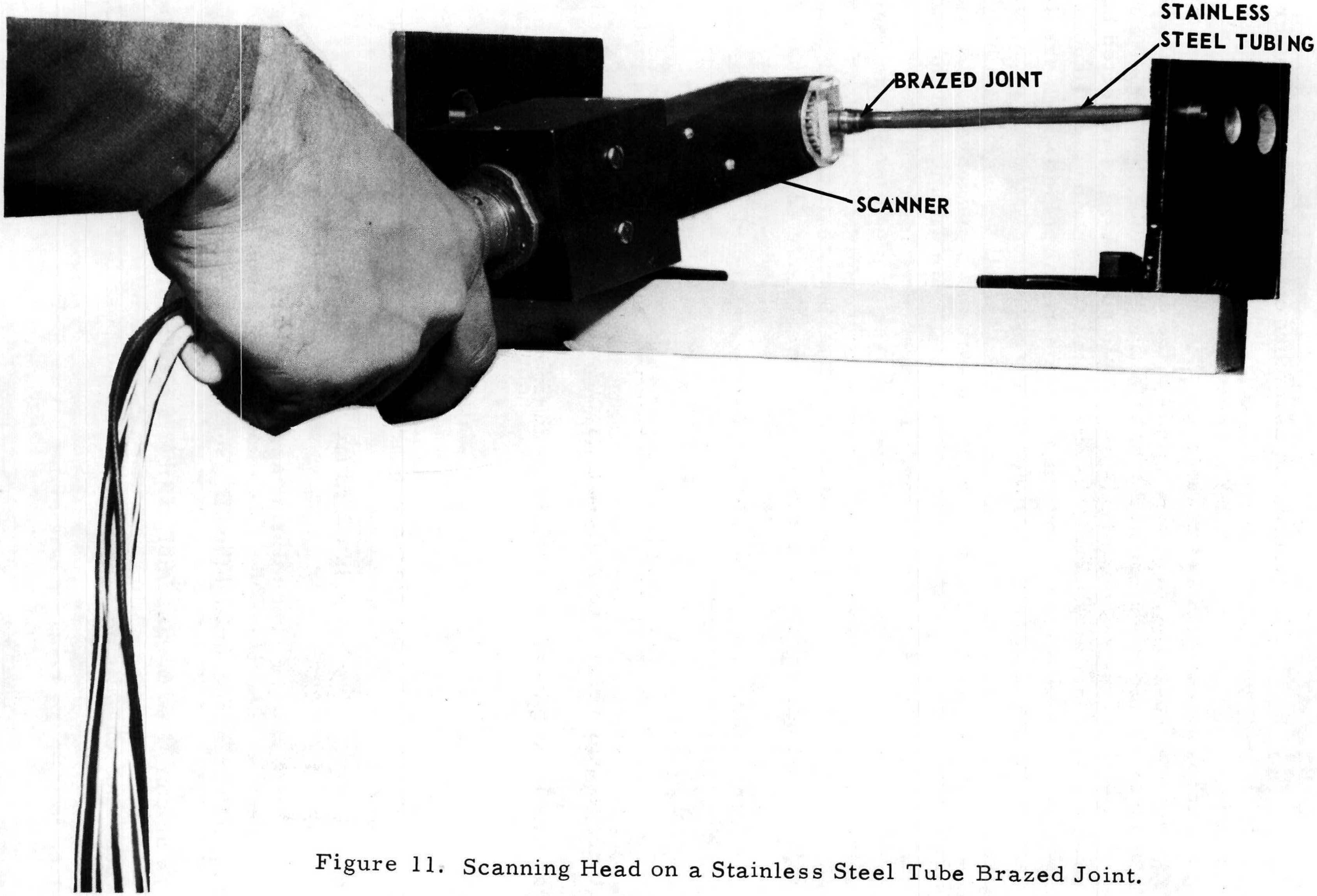


Figure 11. Scanning Head on a Stainless Steel Tube Brazed Joint.

(2) Transducer Assembly

The transducer assembly consists of a transducer and transducer boot (figure 8). The transducer is an ultrasonic crystal assembly that emits an ultrasonic pulse as a result of the applied electrical pulse. The transducer receives portions of this ultrasonic pulse as it is reflected back. Operating in reverse, the transducer generates electrical pulses which are amplified by the receiver. Through the use of timing circuits, all of the signals handled by the receiver, including the initial transmitted pulse, are arranged in the order of their occurrence and are presented as vertical pulses or pips along a time base line of a cathode-ray tube. The transducer specifications are 1/4-inch diameter, 0.225-inch length, approximately 0.30-inch focal length, and a frequency of approximately 8 megahertz.

The transducer boot is a rubber tip that is attached to the transducer by a copper sealing band. The boot contains water which provides sound wave transfer and focusing media. The boot also provides the flixible surface to conform to the tube joint countour variations.

(3) Slipring Assembly (Figure 8)

The slipring assembly transmits and receives signals between the transducer and the ultrasonic flaw detector. A contact ring and slipring comprise the assembly which is electrically insulated from the

threaded case and slug by the outer case. The contact ring is stationary and is electrically connected to the flaw detector, and the slipring rotates and is electrically connected to the transducer. As the slug rotates, continuous contact is maintained between the contact ring and slipring.

(4) Threaded Slug (Figure 8)

The slug houses the transducer and is rotated around the brazed joint while at the same time traversing the tube longitudinally by means of the internal threads of the threaded sleeve. Potentiometers (position sensors) are provided to prevent slug overtravel in either direction and track the slug position. The total slug travel is 0. 500 inches which will cover one joint end.

b. Drive Mechanism (Figure 7). The drive mechanism contains the drive motor, gears, and belt drive assembly.

c. Position and Level Sensors (Figure 7). Position and level potentiometers are located in the scanner between the drive mechanism and the handgrip. The level sensor detects the position of the transducer along the tube, and when the level sensor output reaches the level set in one of the two comparators, a pulse is applied to the interface circuit. The interface circuit voltage applies the proper voltage to the bistable multivibrator. The multivibrator changes state causing the power amplifier to reverse the dc voltage applied to the scanning unit motor. The second comparator performs the same function in the reverse direction after the transducer has traveled the desired number of turns.

2. Limit Control (Figure 1). The limit control detects the movement of the transducer along the brazed tube and reverses the transducer movement after a selected number of turns. The limit control function is performed by the level sensor (located in the scanning unit, figure 7) and the limit control. The limit control consists of two comparators, two interface curcuits, a bistable multivibrator (flip-flop), and a power amplifier.

3. Flaw Detector (Figure 9). The pulse generator of the flaw detector (Immerscope) sends out electrical pulses of very short duration (usually one microsecond or less) at a rate which ranges from 50 to 5000 pulses per second. Since each pulse is of short duration, there exists a long period of time after each pulse when no transmission occurs. During this time, the receiver accepts returning echoes or reflections from the material under test. In addition to this primary function,of shocking the transducer, the flaw detector also presents visual evidence of ultrasonic signals being generated and the reflections of such signals from items under test (A-Scan).

4. C-Scan Converter (Figure 1). The C-scan converter contains circuitry that converts electrical signals from the position sensor (located in the scanning unit) and from the ultrasonic flaw detector to signals that provide a C-scan display on the storage scope. The scan lines that are reproduced on the storage scope aid in locating flaws around the periphery of the brazed tube being inspected and indicate the position of the flaws by displaying a flat picture of the tube circumference.

Thus, as the transducer rotates, a horizontal line is displayed on the storage scope. After one complete revolution of the transducer the horizontal line on the scope is completed, and a pulse from the position sensor is applied to the pulse shaper of the C-scan converter.

The pulse shaper provides a pulse of the required time to blank out the scanning spot (the previously placed horizontal lines remain on the scope face) during the return of the spot for start of the next horizontal line. The output of the pulse shaper is also applied to the sample and hold. For each pulse that the sample and hold receives, it sends a new dc level to the scope vertical display, which is held until the next horizontal sweep begins. For each revolution of the transducer, a new line following below the previous line appears on the scope face.

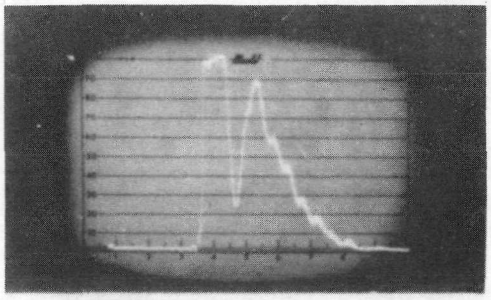
5. Storage Detector (Figure 10). The storage detector receives electrical signals that present a plane view of the transducer echo on the face of the scope (C-Scan). The condition of the area under test is held on the face of the scope until it is erased by the operator. This allows sufficient time for a photographic record to be made of the brazed area.

> NOTE: For Additional Details on System Operation refer to MSFC Technical Manual, Operation and Maintenance, Document Number 85M11077, dated 7 August 1972.

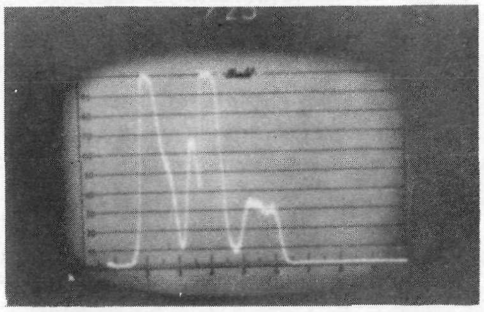
SECTION IV. DEFECT INTERPRETATION

A. A-SCAN

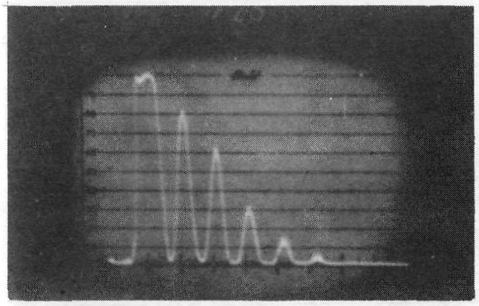
Viewing the A-scan (flaw detector scope trace) is an effective means of evaluating a brazed tube joint. Not only can defective areas be easily detected and sized, but the location of the transducer on the brazed joint can be easily noted. Figure 12 shows the scope traces that occur during a typical joint revolution. It is evident from this figure that the axial location of the transducer is easily determined. Although the location of the transducer on the joint is an important factor in the joint evaluation, the major importance of the A-scan is the distinguishing of tube and sleeve defective areas. A small defective area (less than 0.020 inch in diameter) will not intercept the full area of the ultrasonic beam and, therefore, can only be detected by a drop in amplitude of the back surface reflections. This drop in amplitude can be easily recorded, but variations in a braze line thickness may cause an amplitude drop of the same magnitude. Therefore, a small defective area cannot be distinguished from a braze thickness variation by a recorder, but the two conditions can be easily distinguished by the rate of the amplitude loss as viewed on the scope trace (A-scan). A defective area will cause the signal amplitude to change rapidly, whereas, an eccentricity results in slow-changing amplitude variations. Figure 13 shows a scope trace comparing a good braze and defective areas.



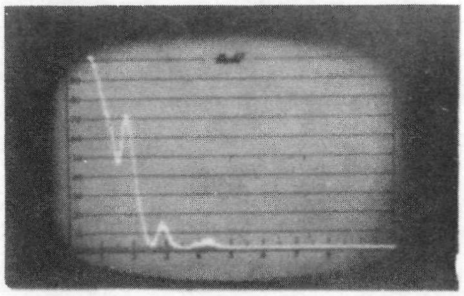
a. Transducer off of sleeve-on tube. (Characterized by the tube ringing pattern; 5. 5 on scope trace.)



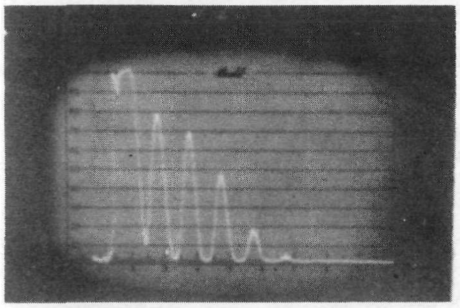
b. Transducer starting onto sleeve. (The tube reflections decrease and the sleeve top surface reflection starts to occur; 1. 5 on scope trace.)



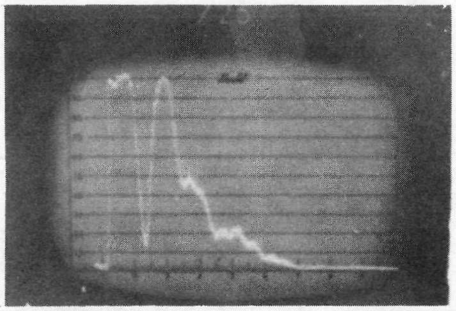
c. Good Braze "A" area. (Characterized by strong back surface reflections at 3, 4, and 5 on the scope trace. This trace will occur for 5 revolutions.)



d. Transducer on hump. (Characterized by slow shift to the left of the scope trace. Coming off of the hump, the trace returns to the right.)

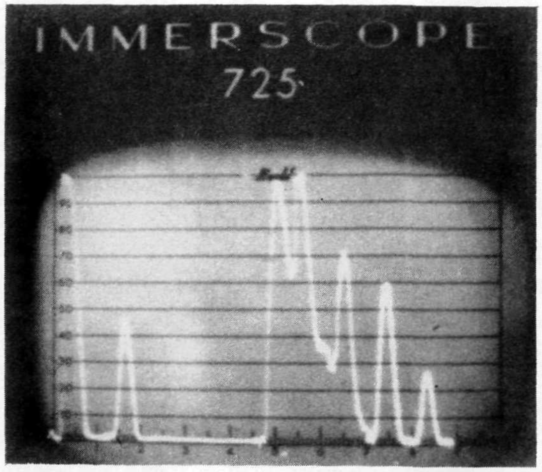


e. Good braze "B" area. (The same trace as good braze on "A" area. This trace will occur for 2. 5 to 3. 0 revolutions, if the tube insertion length is proper.)

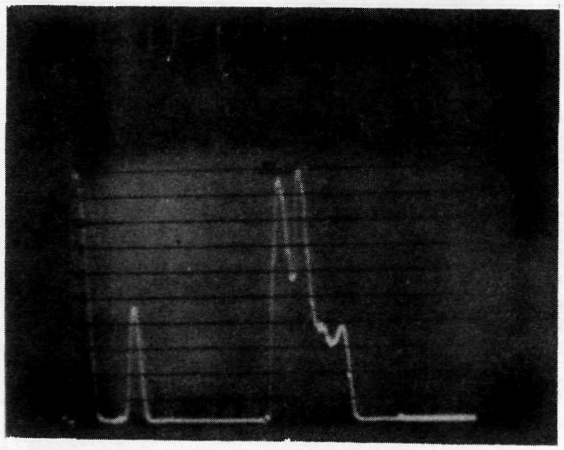


f. Transducer on sleeve past the "B" area. (Same trace as for the transducer on the tube, Figure a, except that there will be a start time difference in the trace.)

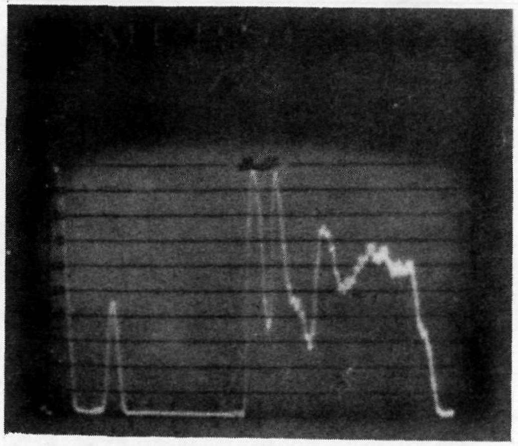
Figure 12. Flaw Detector Scope Trace Patterns.



a. Scope trace indicative of good braze



b. Defective area. (Note that the back surface reflections are completely blocked. A defect will cause the back reflections to drop out very quickly. They will return as abruptly when the defective area is crossed.)



c. Ringing pattern characteristic of defective areas larger than 0.060 inch in both X and Y dimensions

Figure 13. Scope Patterns Characteristic of Defective Areas.

B. C-SCAN

1. General. The C-scan presentation provided by the storage detector (figure 1) gives the size and location of a defective area; and, in addition, can furnish a permanent record of the inspection results. The C-scan cannot be relied on to detect defective areas less than 0.020 inch in diameter, but by being capable of detecting defects of that size, the equipment meets the design specifications.

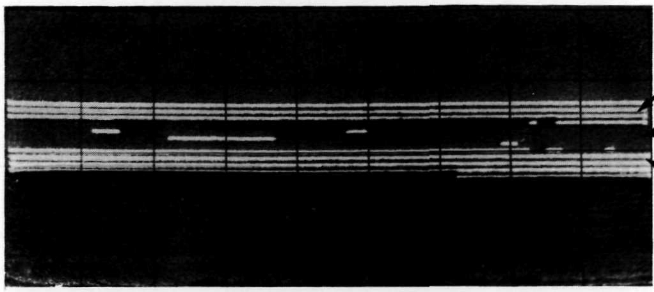
All C-scan presentations have basic similarities, regardless of the tube size and configuration undergoing inspection. Figure 14 shows C-scan recordings of four different 3/8-inch diameter brazed tube joints which have a variety of defective conditions.

2. Defect Location and Size Determination. The size of the flaws shown on the C-scan presentations on figure 14 were determined by using flaw detector (figure 1) settings that gave pre-planned information of known size and location. This operation was accomplished as follows:

a. For each 0.020 inch of axial flaw dimension, one horizontal sweep line was broken (blanked out) in the area of the flaw.

b. Each 0.050 inch of scope presentation represents 0.020 inch of circumferential flaw dimension.

c. The circumferential location of the flaw was determined by the horizontal sweep line where the defect indications appear.

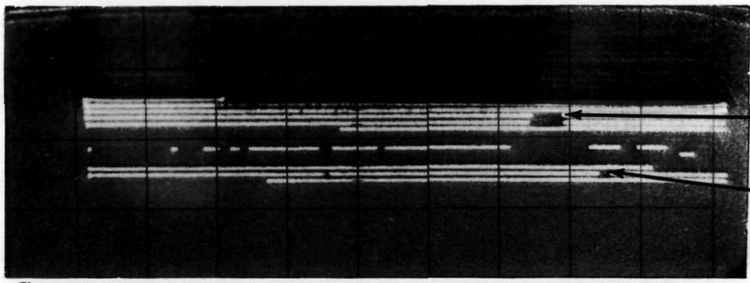


"A" AREA - 4.5 TO 5.0 PASS LINES

HUMP - 6.5 TO 7.5 PASS LINES

"B" AREA - 0 TO 5 PASS LINES DEPENDING ON TUBE INSERTION LENGTH. THE PROPER ("B" area width of 0.125 inch) TUBE INSERTION WILL RESULT IN 2.5 TO 3.0 PASS LINES.

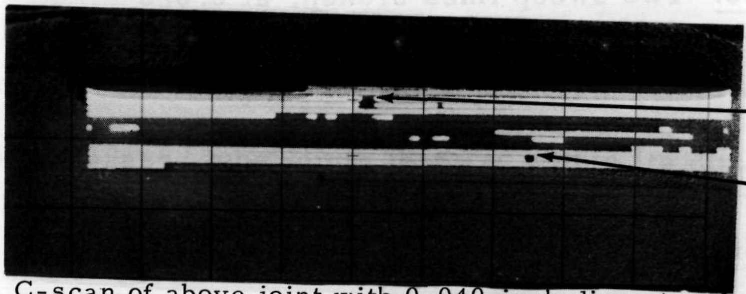
a. C-scan of 3/8-inch diameter tube joint with no defective areas.



0.040 x 0.080 inch diameter defect.

0.015 inch diameter defect.

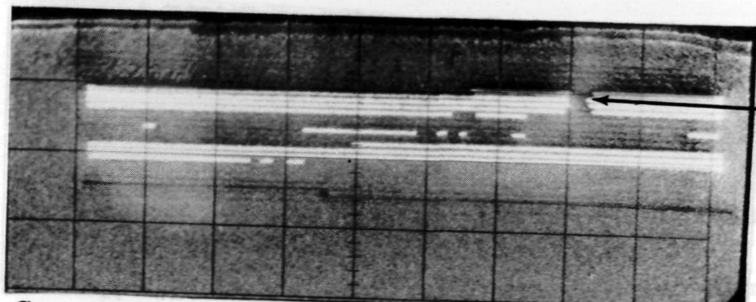
b. C-scan of above joint with 0.040 x 0.080-inch diameter defect located in "A" area and 0.015-inch diameter defect located in "B" area.



0.040 inch diameter defect.

0.010 inch diameter defect.

c. C-scan of above joint with 0.040-inch diameter defect located in "A" area and a 0.010-inch diameter defect located in "B" area.



0.185 x 0.060 inch diameter defect.

d. C-scan of above joint with 0.185 inch x 0.060-inch diameter defect located in "A" area.

Figure 14. C-scan recordings of four different 3/8-inch diameter brazed joints.

d. The axial location of the flaw center was determined by relating (1) the numbers of horizontal sweeps required to reach the flaw center to (2) the 0.030 inch axial moveover per each circumferential scan. (See paragraph III B1.)

EXAMPLE

An example of the discussion presented in paragraphs a, b, c, and d above as to how the information is applied is as follows:

(Refer to figure 14b.)

Actual flaw dimensions: Two sweep lines broken, at 0.020 inch per sweep line equals 0.040 inch flaw.

Circumferential flaw Dimension: A flaw circumference of 0.200 inch (as measured from figure 14b) at 0.020 inch per each 0.050 inch equals 0.080 inch of flaw.

Circumferential location: Read directly from the trace to equal 260° from scan start.

Axial Location: As shown, there are 3.5 sweep lines to the center of the flaw, at 0.031 inch per line equal 0.105 inch into the "A" area.

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

The ultrasonic brazed tube scanner is a reliable and accurate inspection system. The system is capable of scanning 3/16- through 5/8-inch-diameter in union, tee, elbow, and cross configuration brazed joints. The joint scan time of 3 to 4 minutes coupled with the maximum setup time of 30 minutes gives this system a clear inspection time advantage over other methods. Tests performed on tube joints containing preplaced defects confirmed the ability of the test method to reliably detect defects 0.020 inch in diameter and larger. The smaller defect which can be detected is 0.008 by 0.010 inch. Both the A- and C-scan presentation methods are reliable and accurate in locating defective areas.

The ultrasonic brazed tube scanner is recommended for the evaluation of all brazed tube joints that are within its dimensional capabilities. This recommendation is based upon the scanning and rapid inspection time capabilities of the system and the ability of ultrasonic test methods to detect defects which are not related to material density changes.

APPROVAL

ULTRASONIC SCANNING SYSTEM FOR INSPECTION OF BRAZED TUBE JOINTS

By J. L. Haynes and N. A. Maurer

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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